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Filamentary charge carrier injection in heterogeneous oxide systems

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Resistive switching effects take place in a variety of heterogeneous oxide systems. Thus a study of mechanisms of electron transport in these systems is important. We assume that electron transport in oxide systems with resistive switching effects is due to space charge limited current observed under charge carrier injection from electrode. We experimentally observed that current through our structures doesn't depend on the electrode surface area, thus we believe that we have a filamentary charge carrier injection. In this work a phenomena of filamentary charge carrier injection in bilayer structures (based on a sequence of TiO_2 and Al_2O_3 layers) is experimentally observed by means of tunnel atomic force microscopy. Obtained patterns of current "pinching" formation are analyzed.

The results of our study of resistive switching in bilayers based on a sequence of TiO_2 and Al_2O_3 thin oxide layers [1] indicate that the resistive-switching mechanism is due to electronic processes and is not related to thermal or thermochemical processes. Measured *I-V* characteristics of these systems are nonlinear and symmetrical (regarding polarity of applied bias). An analysis of *I-V* characteristics shows that they are linearized in a double logarithmic scale with several characteristic parts ($I \sim U^n$), corresponding to linear, square, and power dependences with $n \geq 3$. This is typical for space charge limited current in high resistivity materials with low carrier mobility and long dielectric relaxation time. The fact that current through our structures doesn't depend on the electrode surface suggests that we have a filamentary charge carrier injection [2].

To study the phenomena of filamentary charge carrier injection we measured current distribution over the surface of bilayers by means of tunnel atomic force microscopy (tAFM). We experimentally observed that after scanning the surface of bilayers with voltage applied between the microscope probe and the bottom electrode, areas could be associated with current "pinching" appeared. These areas are visualized in a tunnel atomic force microscopy regime on a current distribution as conductive regions and formed in places of the surface previously scanned with bias application. The value of voltage starting from which current "pinching" could be observed roughly corresponds to the voltage at which switching the resistance takes place according to the *I-V* characteristics measured on a top electrode of the structure. Changing the polarity of applied bias leads to the partial disappearance of the conductive regions previously induced by voltage application and forming conductive regions in another places of the structure. Thus, we experimentally observe reversible formation of conductive areas in metal-oxide thin film bilayers and associate them with filamentary charge carrier injection effect.

Based on the findings of the measured size of current "pinching" regions, we try to explain the main parameters of resistive switching in heterogeneous oxide systems. Among these parameters are a ratio of the resistances in high / low resistive states and the value of switching voltage. In the context of our approach we make an assumption regarding the main limiting factor influencing the size of filamentary charge injection areas.

1. N. Andreeva, A. Ivanov, A. Petrov, *AIP Advances* **8**, 025208 (2018).
2. K.C. Kao, W. Hwang, *Oxford: Pergamon Press* (1981).

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